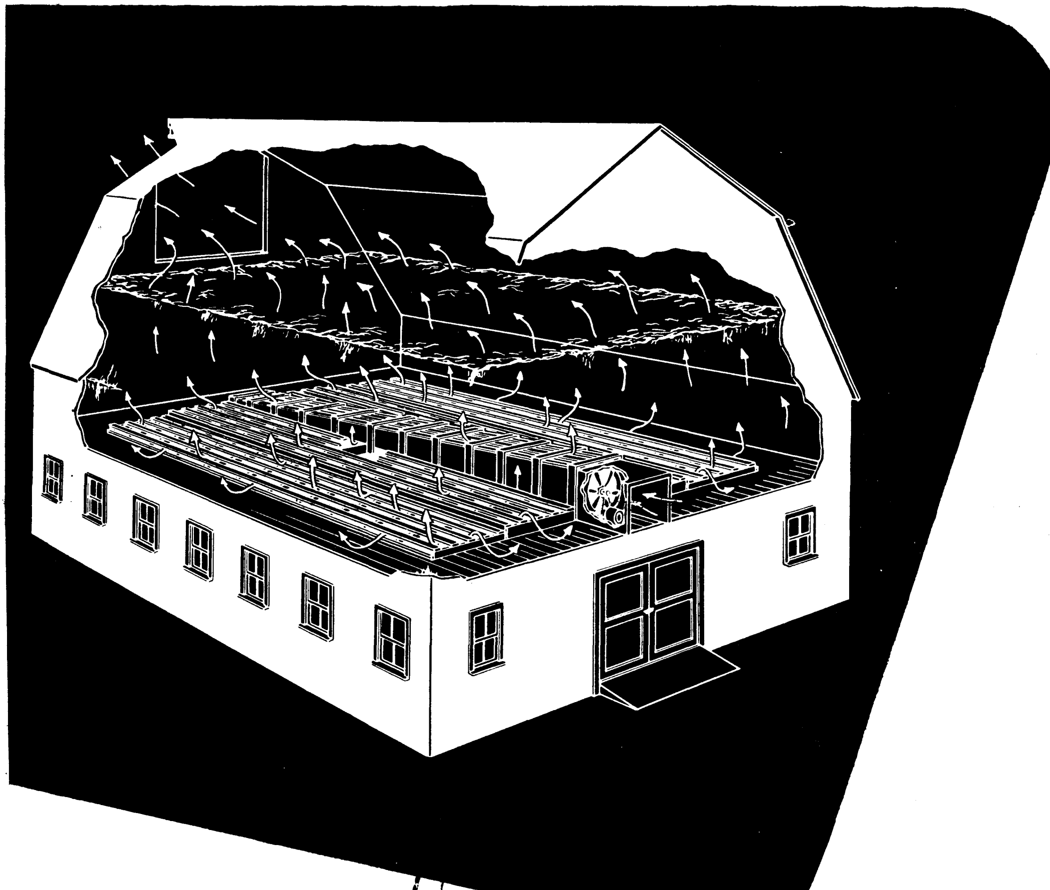
DRYING FORAGE
BY FORCED VENTILATION



Farmers' Bulletin No. 2028

U. S. DEPARTMENT OF AGRICULTURE

WEATHER HAZARDS during the harvesting of forage crops are reduced, and the quality and nutritive value of the hay are retained more effectively if final curing is done in the barn by forcing air through the hay. Driers can be used anywhere in the country where hay can be field-cured to 50 percent or less moisture.

Alfalfa is the legume most widely dried, but cowpeas, soybeans, and lespedeza also may be successfully dried by forced-air ventilation. Many of the grasses used for hay have been dried with good results. In experiments, hay dried by forced-air ventilation has shown feeding values for dairy cows equal to or better than field-cured hays.

Unheated or heated air may be used in drying systems. Oftentimes the air-distribution systems used in barns are of the slatted-floor type. Drying installations may be used outdoors as well as in a barn.

This bulletin gives information on the types of drying systems and on installing and using them, and lists the safety precautions necessary when heated air is used. Figures and estimates on costs of installations, fuel, electricity and other costs of operation, and on labor and equipment requirements, also are presented.

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DRYING FORAGE BY FORCED VENTILATION

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WEATHER HAZARDS IN FORAGE HARVESTING

Forage ranks third in value among farm crops. About 100 million tons are produced each year on 74 million acres of land. To obtain the highest nutrient value and maximum yield, the farmer must cut the forage at the proper stage of maturity. Oftentimes when this stage occurs the weather is bad. Unfavorable weather during harvest may bring total or partial loss of the hay crop that is left in the field to cure. Rain and dew on cut forage will result in loss of leaves, and of protein, minerals, and carbohydrates. Sunshine following rain or dew causes bleaching and loss of carotene. It is estimated that because of the weather hazards enough protein is lost each year during curing of hay to furnish the protein requirements of 7½ million cows for 6 months.

To reduce the hazards of weather during harvesting and to help retain the quality and nutritive value of the crop, hay drying by forced ventilation has been developed.

ADVANTAGES, DISADVANTAGES, AND LIMITATIONS OF FORCED-AIR DRYING

An advantage of forced-air drying is that the hay need stay in the field only a short time. The farmer, therefore, can harvest more of the crop at the proper stage of maturity, plan farming operations better, and lessen the hazards of weather. Another advantage of this

system is that it preserves more of the nutrients, because the hay is removed from the field before excessive leaf-shattering and nutrient losses occur. Heating and danger of fire are reduced, as hay put on the barn drier is kept cool until dried to a moisture content safe for storage. An additional advantage is that more barn-dried hay can be put in a given space because partially cured hay settles more than field-cured hay during storage.

A disadvantage of this system is that it places a heavier load on hay-handling equipment because of the extra weight of the moisture in the green forage. The rate of drying and the quantity of forage that can be dried satisfactorily at one loading depend on the amount of moisture to be removed and the amount and drying capacity of the air supplied (table 1). For instance, at 80° F. and 40 percent relative humidity, it would take 3.9 days to dry 30 tons of hay. If the temperature was 70° and relative humidity 60 percent, it would take 8.2 days. Finally, the farmer must invest in equipment and fuel if he desires to add supplemental heat to the drying air to insure drying at all times, and he must take proper precautions in constructing and operating the equipment to remove the danger of fires from this equipment.

TABLE 1.—*Effect of changes in weather conditions on rate of drying of 30 tons of dried hay stored at a moisture content of 40 percent, wet basis, in a 1,200-square-foot mow and dried by air delivered at 18,000 cubic feet per minute*

Temperature (° F.)	Relative humidity	Time for drying
	Percent	*Days*
70	40	4. 6
70	50	5. 9
70	60	8. 2
80	40	3. 9
80	50	5. 0
80	60	7. 0

HAY-DRIER SYSTEMS

In this method of harvesting, hay is partially dried in the field, and the final curing is done by a drier that forces heated or unheated air through the hay. The necessary equipment consists of a blower or fan with power unit and controls and an air-distribution system. The air-distribution system is usually installed on the floor of the mow, and the partially cured hay is placed on top of it. The motor-driven blower forces air through the distribution system and up through the hay. The air removes moisture as it passes through the hay (fig. 1).

WHERE HAY DRIERS CAN BE USED

Forced-air hay drying is adaptable to all sections of the country where hay can be field-dried to 50 percent moisture content or lower. Although the principle of operation is the same for all forced-air systems, modifications in construction may be required to meet indi-

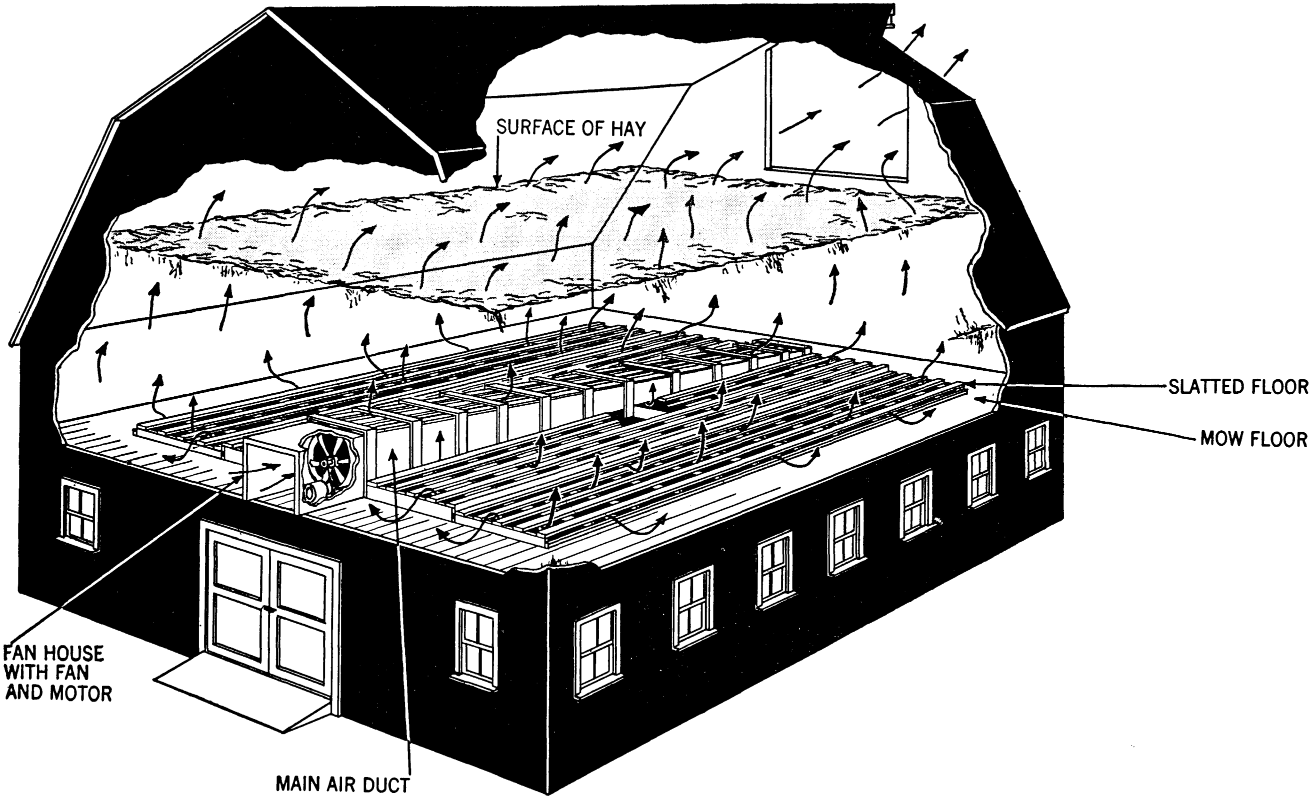

Figure 1.—**Forced-air drying system, showing paths of air in drying hay.**

vidual problems. The use of supplemental heat may be advisable where high humidity and adverse weather persist during harvesting and curing of forage.

Before making an installation, it is very important that the services of an individual thoroughly familiar with the design of forced-ventilation hay driers be obtained. These systems are usually "tailor-made" to fit individual barn measurements and to meet special conditions found on individual farms. This service can be obtained through county agents, an electric-service organization, the agricultural engineering departments of the various State agricultural extension services or agricultural experiment stations. The advice of a safety engineer should be obtained on methods of minimizing fire and other hazards. All electrical equipment should bear the approval stamp of the Underwriters' Laboratories and should be installed to comply with safety regulations.

CROPS THAT CAN BE SUCCESSFULLY DRIED

A wide variety of forage crops have been successfully dried by forced-air ventilation. Alfalfa is probably the legume most widely dried, although cowpeas, soybeans, and lespedeza are being successfully handled this way. Many of the grasses used for hay are being dried, and good results are reported.

Chopped hay may pack a little tighter than long material when put on the drier. Experience has shown that a system designed for an 8-foot depth of long hay will handle about 6 to 8 feet of the same material chopped to a length of 2 to 4 inches. Hay should not have a moisture content above 35 percent when baled. Proper stacking is essential in drying baled hay. Bales should be loosely tied, but still tight enough that they will not fall apart with reasonable handling. They should be stacked so that spaces between bales are as small as practicable and are covered by the arrangement of the layers above. Canvas covers over the top and part of the way down the sides of the stack of bales have been used to promote uniform drying.

AIR-DISTRIBUTION SYSTEMS

Construction of slatted ducts and floors

Air-distribution systems most generally used in barns are of the slatted-floor type. They are usually designed for 15 to 20 cubic feet of air flow per square foot of floor area used in drying hay, and an air resistance through the drying system and hay of less than 1-inch water column pressure. The slatted-floor system consists of a main air duct with a slatted floor extending out from the duct, covering part of the mow floor (fig. 2).

The slatted floor is supported by joists that rest on the mow floor. The main duct in this system is tapered in height from the fan to the far end to provide more uniform air distribution to the system. The slatted floor usually consists of two sections on each side of the main duct; the section next to the main duct is fastened to it and the one next to the wall is movable to make cleaning easier. The section of the slatted floor next to the main duct is usually 2 inches higher than the section next to the wall. The air is forced into the main duct by the

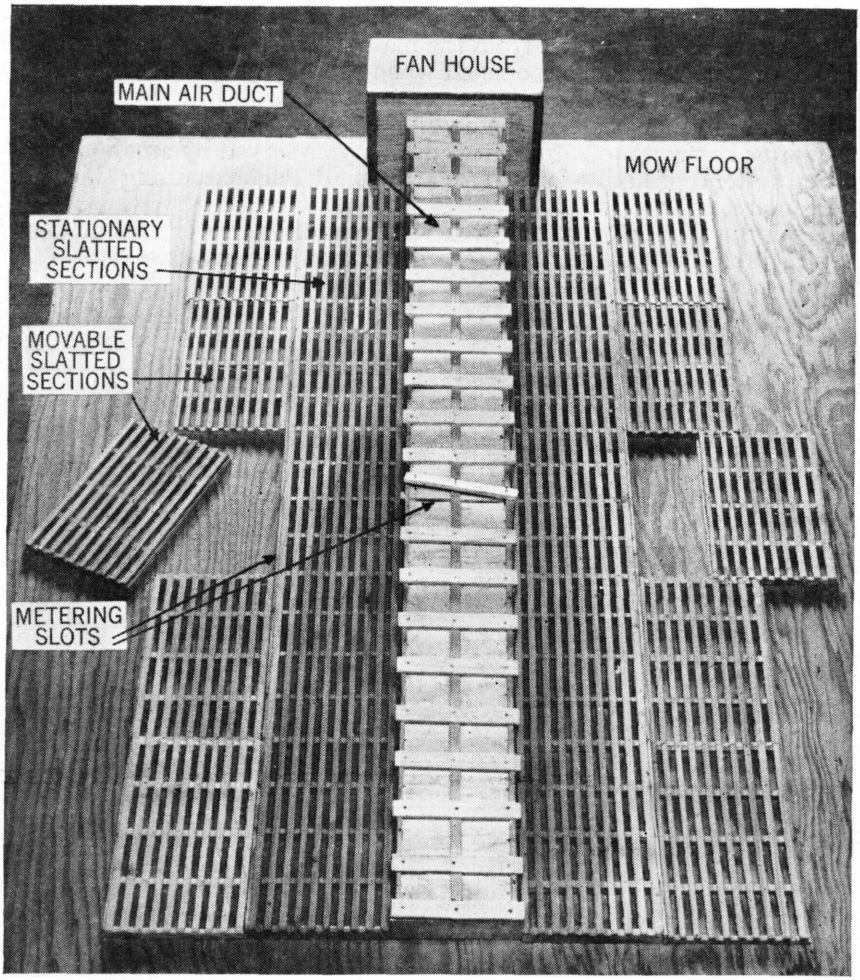

***Figure 2.*—Model of a slatted-floor drying system.**

blower, which is located in one end of the duct, and is distributed to the slatted floor through an opening at the bottom of the side of the main duct. A metering opening or crack is also provided between the sections of the slatted floor to regulate the air flow at these points. The height of the sections and the width of the metering cracks must be determined in the design of the individual system. The slatted floor is not extended all the way to the wall, and the distance between the wall and the edge of the slatted floor is determined by the type of wall and the depth to which hay can be stored. Openings are left in the top of the main duct to allow some of the air to pass up through the hay on top of the duct. When necessary, the main duct is placed along one side of the mow and the slatted floor is extended from only one side.

In systems for deep mows, the main duct may be of uniform size its entire length. Doors are provided in the duct to cut off the air flow

to the slatted floor and to open the duct at or near the top to allow all of the air to be distributed from the main duct. The lower doors are closed and the upper doors opened when the hay on the floor is about 10 or 12 feet deep, to reduce the loss of air up the side of the mow when additional hay is placed on the drying system (fig. 3).

Narrow barns up to 20 feet in width may be served by an air-distribution system consisting only of a slatted main duct extending through the center of the mow.

Drying systems for round structures should have the main duct running vertically through the center of the structure (fig. 4). The

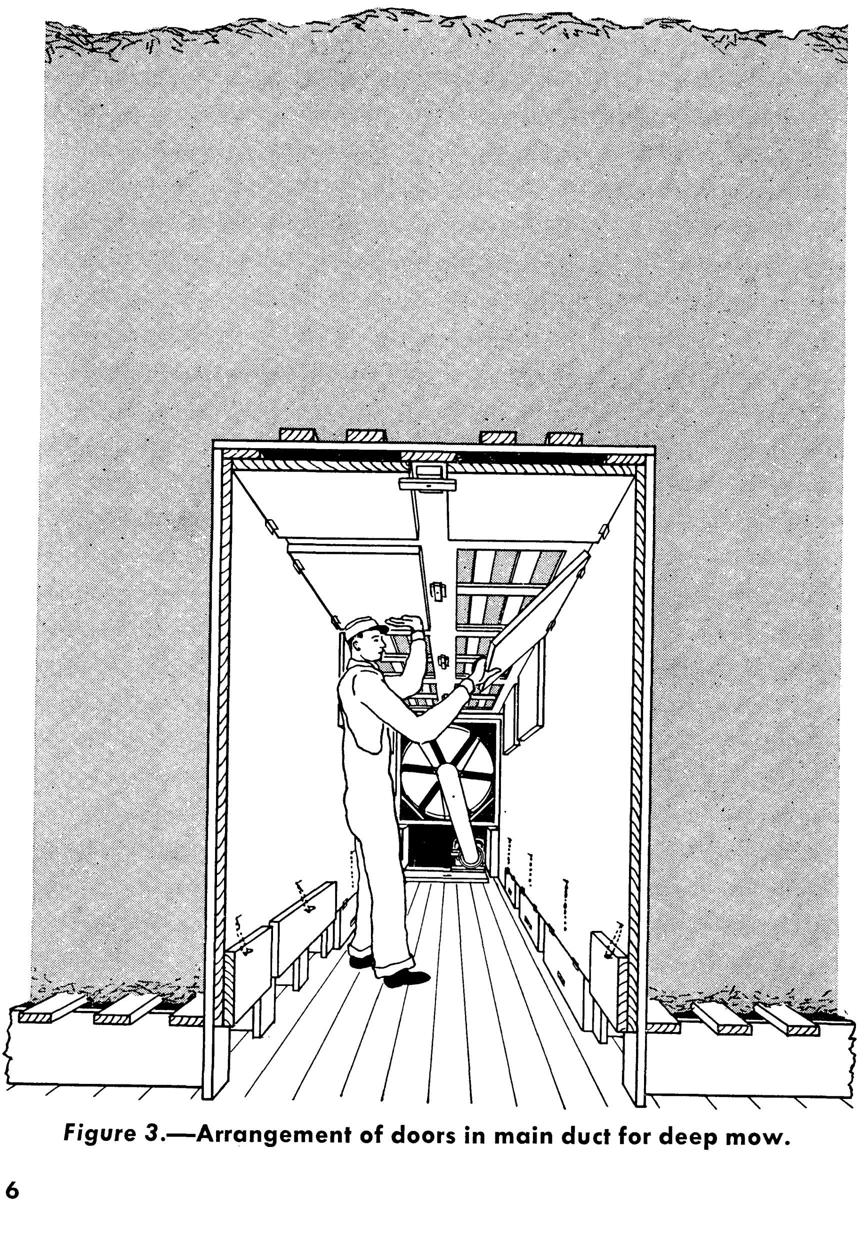

***Figure 3*.—Arrangement of doors in main duct for deep mow.**

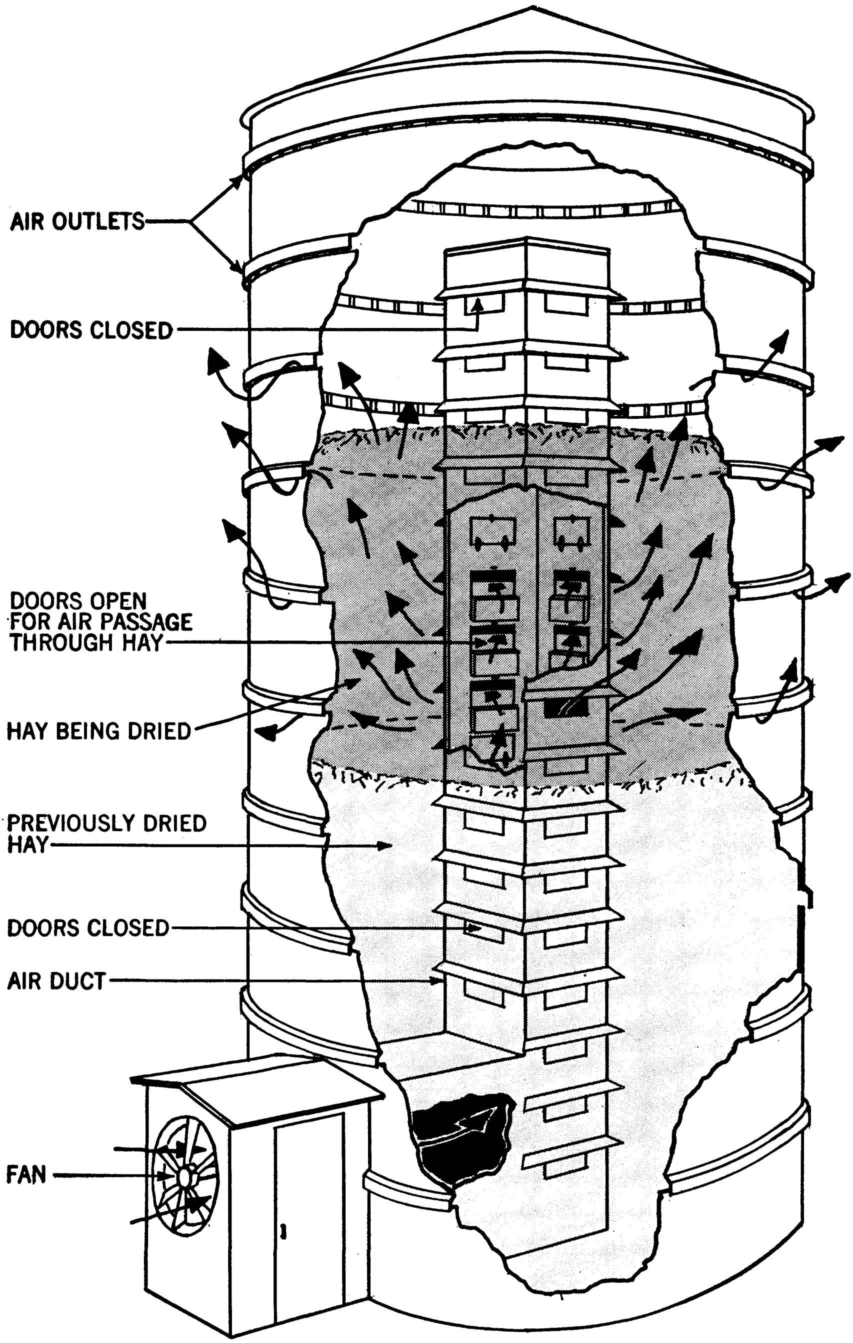

Figure 4.—**Round structure with forced-air drying system.**

air duct is closed off below the top of the hay that is to be dried to permit proper distribution of the air through the hay. The air is usually supplied through a tunnel to the main duct at the base of the structure. Air passes from the main duct laterally through the hay and out the openings on the side of the structure. It is desirable to close off the openings of the main duct to forage already on the drier and previously dried so that air may be directed only through the uncured forage.

Drying installations may be used outdoors as well as in a barn (fig. 5).

When drying forage outdoors tarpaulins or other covers should be provided for protection against rain (fig. 6).

Types of fans

The types of blowers or fans most commonly used with the drying systems are the propeller type (fig. 7), the lightweight forward-curved-blade type (fig. 8), and the backward-curved type (fig. 9).

The propeller and the forward-curved-blade type fans are less expensive and are in general use. The forward-curved-blade fan will tend to overload the motor when there is a small quantity of hay on the drier. Means, such as doors next to the fan, should be provided and used when needed to prevent this overloading. The backward-curved-blade fan is particularly adapted for use where high static pressures are encountered.

Types of power

The fan is usually driven by an electric motor or a gasoline engine. The electric motor requires less attention during the drying period and

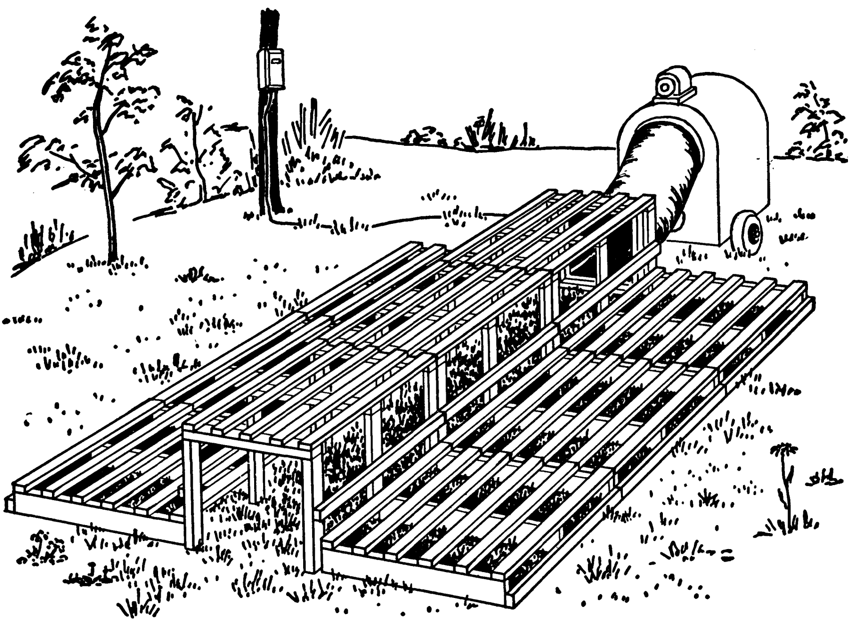

Figure 5.—Outdoor drying installation.

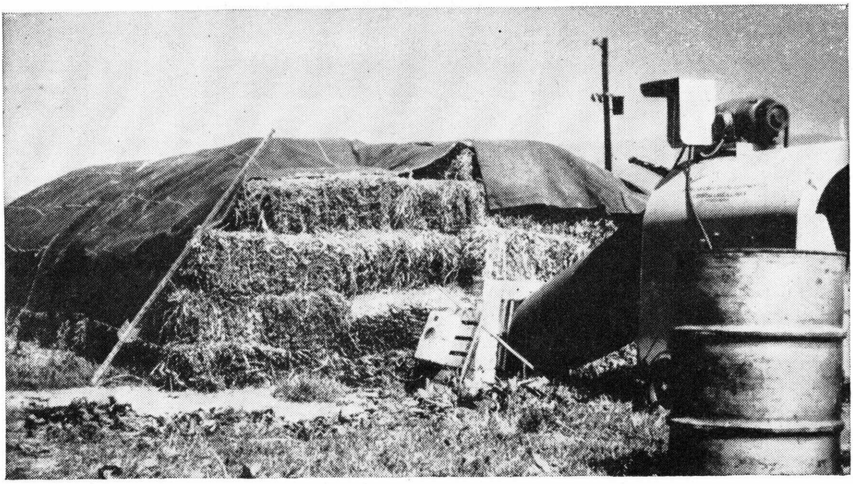

Figure 6.—**Tarpaulin covering baled hay on outdoor installation.**

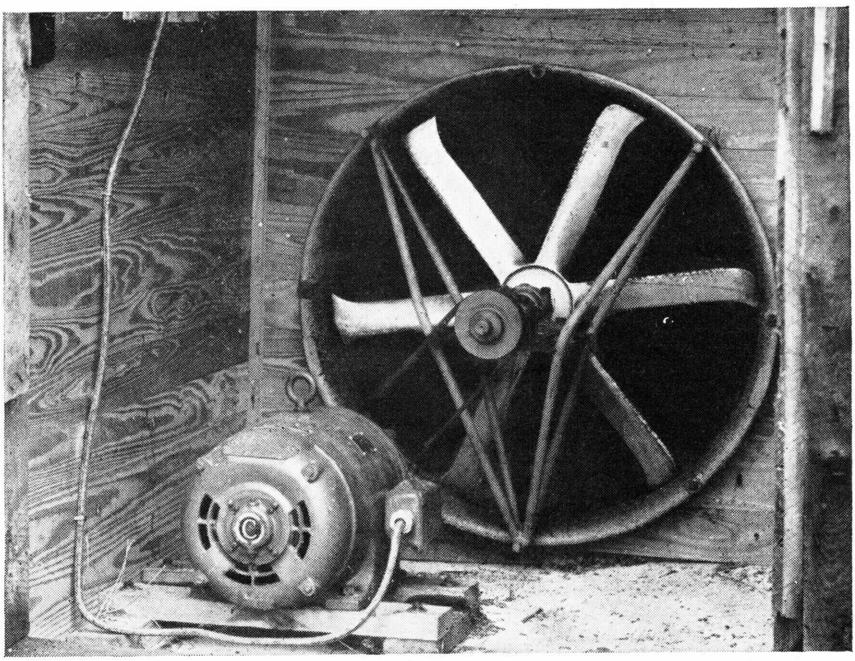

Figure 7.—**Propeller-type fan with belt-connected motor. The protective screen covering the fan housing as a safety precaution has been removed to show construction features.**

is simpler to start and stop with automatic devices. When a gasoline engine is used, the heat given off by the cooling system and the exhaust of the engine is taken up by air passing through the fan. This raises the temperature of the air a few degrees and increases the drying rate

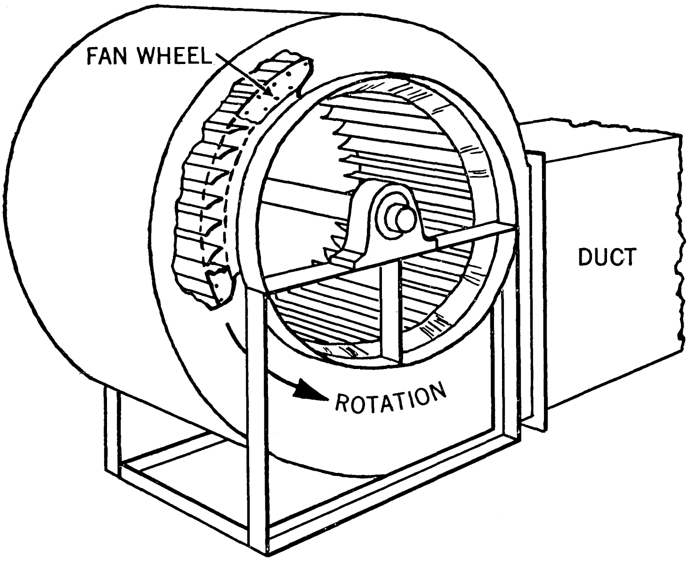

Figure 8.—**Forward-curved-blade centrifugal fan.**

slightly. However, some investigators consider the gasoline engine a fire hazard. The ease of operation and dependability of the electric motor have caused it to be selected more generally for use in hay drying.

Supplemental heat

If air used to dry the hay on any of these drying systems is heated before it is forced through the hay, it will remove moisture faster. Heated air makes it possible to dry the hay at any time, regardless of the weather (fig. 10). Thus, more hay can be dried with a hay-drying system and more nutrients will be retained, particularly with legume hays, when the total drying time by forced-air circulation is less than 3 days. The use of supplemental heat also adapts forced-air drying to humid climates where otherwise it would not be practicable.

The use of supplementary heat increases the initial cost (table 2) of the drying installation by the amount of the cost of the heating unit, or between $700 and $1,400. The operating cost (table 3) may or may not be increased, depending on weather conditions and the relative cost of fuel and electricity. In very humid climates the addition of a heating system may reduce the drying time to such an extent that the saving of electricity for operating the fan may pay for the cost of the fuel. The use of supplementary heat makes it necessary to reduce the drying time in order to preclude damage from mold. Many molds grow best at temperatures slightly above that of the atmosphere. The use of supplemental heat, therefore, often speeds the growth of mold unless the drying time is reduced to 3 to 4 days. Some of the other disadvantages of using supplemental heat are: more personal attention is required; the bottom layers of hay may be overdried, making it harder to handle; and the fire hazard is increased. The fire hazard can be reduced to a minimum, however, in a system equipped with

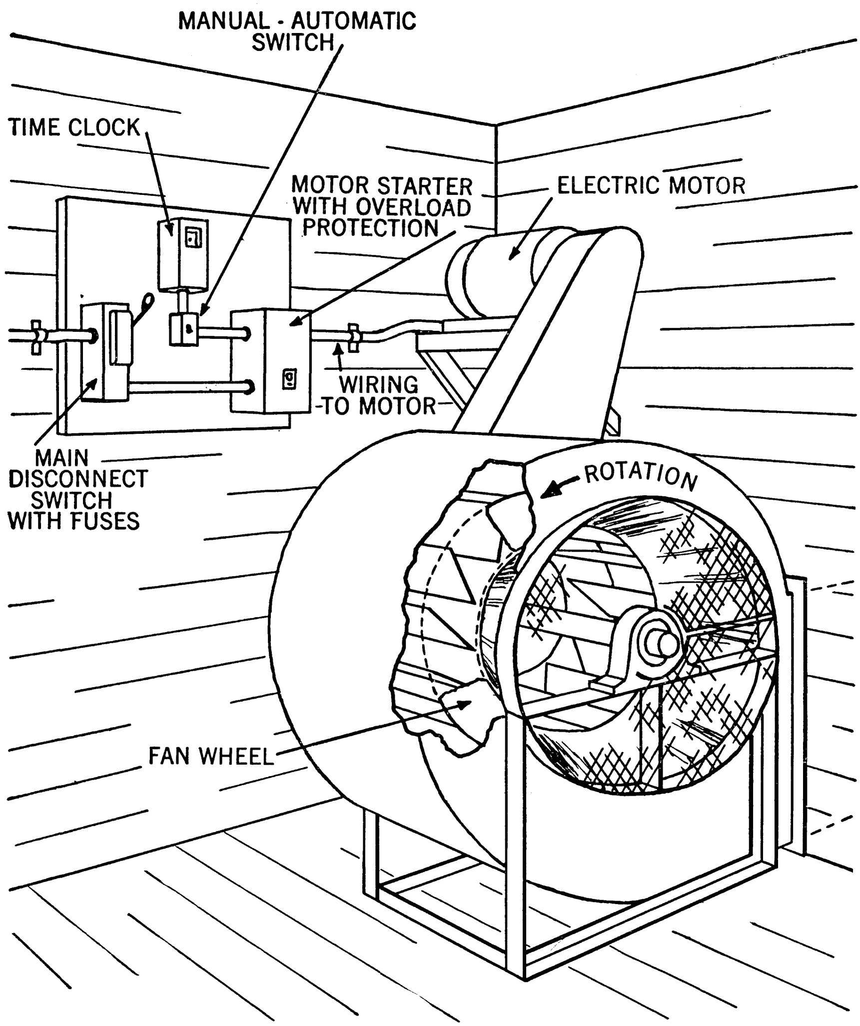

***Figure* 9.—Backward-curved-blade centrifugal fan with motor and controls.**

proper safety devices. In general, supplemental heat is a necessity in some sections and is good insurance against bad drying weather in others.

Many portable crop driers are adaptable for use in drying other farm crops as well as forage. Before one selects a drying unit, he should consider other crop drying needs that may develop.

In recent years manufacturers have been assembling and placing on the market drying units consisting of fan, motor, and heating unit. In general, the heating units are of two types: those with a heat exchanger (fig. 11) and those without (fig. 12).

Where a heat exchanger is used, the heat generated by burning some type of fuel is transferred to the air stream and the combustion gases

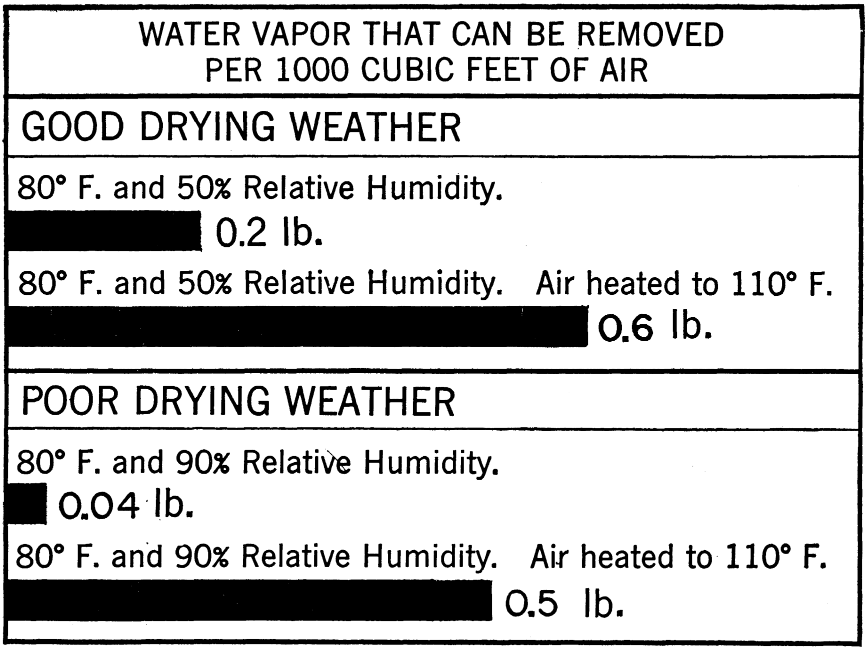

***Figure 10.*—More moisture can be removed by heated air.**

TABLE 2.—*Initial cost of comparable installations*[1] *of barn-drying systems, with and without supplemental heat (approximately 1,200 square feet of mow floor area)*

Equipment and labor	Cost	
	No supplemental heat	With supplemental heat
	Dollars	*Dollars*
Drier	----------	1,200 to 2,000
Fan	190 to 230	(2)
Motor	171 to 250	(2)
Motor controls	25 to 50	(2)
Drive	21 to 25	(2)
Installation	[3] 50	[3] 15
Distribution system:		
Lumber	70	50
Labor	[4] 50	[5] 40
Total	577 to 725	1,350 to 2,105

[1] These prices were taken from manufacturers' price lists for units that would be recommended for the same size installation and are subject to change.
[2] Normally included in drier.
[3] This does not include the cost of bringing power to the barn, since the distance involved makes this cost vary widely.
[4] 50 man-hours at $1.00 per hour.
[5] 40 man-hours at $1.00 per hour.

TABLE 3.—*Fuel and electricity costs for drying 40-percent-moisture hay, wet basis, to 30 tons dry hay in a 1,200-square-foot mow, using air delivered at 18,000 cubic feet per minute*

Temperature (° F.)	Relative humidity	Approximate time for drying	Cost of electricity [1]	Cost of oil [1]	Total operating cost	Operating cost per ton
	Percent	*Days*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
70	65	12.5	45.00	[2]	45.00	1.50
90	35	3.1	11.25	29.64	40.89	1.36
110	19	1.9	6.90	34.87	41.77	1.39
130	10	1.4	5.10	37.44	42.54	1.42

[1] Cost of drying computed with electricity at 2.5 cents per kilowatt-hour and oil at 13 cents per gallon.
[2] No supplemental heat.

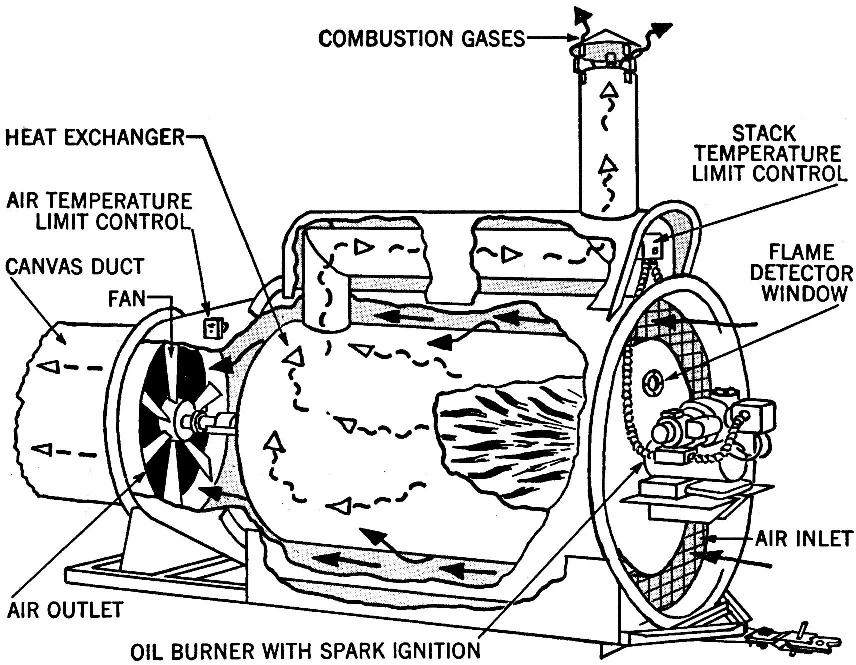

***Figure 11*.—Drying unit with heat exchanger.**

exhausted into the surrounding atmosphere. These units are usually more expensive and lose more heat. In any installation where heat is used, adequate fire-extinguisher equipment should be available. Where fuel oil or gasoline is used, CO_2 or dry chemical extinguishers should be ready for immediate use. Both of these types of chemicals are also safe for use on electrical-equipment fires.

Where no heat exchanger is used, the combustion gases go into the air stream delivered to the crop. With certain fuels and some crops

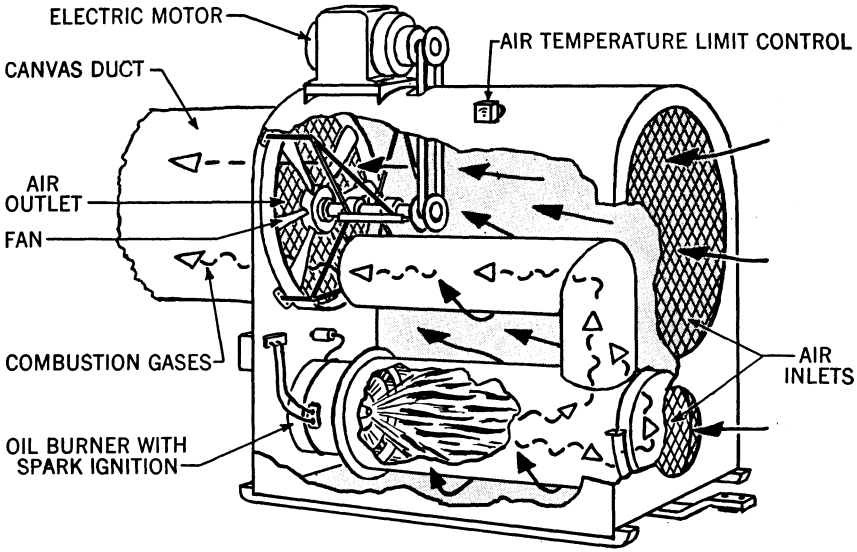

Figure 12.—**Drying unit without heat exchanger.**

this is objectionable, and in any case a very clean operating burner is required. Both types are usually portable and may be moved from place to place, as required. Such units are available in a number of sizes, from one with a fan powered by a 3-horsepower electric motor to the large sizes requiring a tractor or gasoline engine of approximately 25-horsepower output.

One who is contemplating the purchase of such a unit should satisfy himself that the unit has adequate safety devices. A crop drier should have some method of shutting off the fuel if the temperature goes too high. The flow of fuel should also be stopped in case the fire goes out or in case the main blower stops. The combustion gases should be adequately screened to prevent sparks or hot particles, as insects and foreign materials, from getting into the air stream that dries the crop. The unit should be connected to the drier system by a duct of fire-resistant material and should be at least 10 feet from the building housing the crop (fig. 13).

Grass around a fuel-burning power unit is a serious fire hazard. Dry grass and combustible material should be scraped clear of the unit and the immediate surrounding area.

BUILDING REQUIREMENTS

The forced-air ventilation system can be installed in almost any type of haymow or hay shed if certain conditions are met. The roof of the building should be in good condition to prevent leakage and consequent spoilage of the hay. It is necessary to have a tight floor; otherwise, the air will go down through the floor instead of up through the hay. A well-laid tongue-and-groove floor or one with composition roofing over a wood floor containing small cracks is satisfactory. If a drier is to be installed in a shed, a hard, dry, smooth earth floor is satisfactory with adequate drainage around the building. A properly

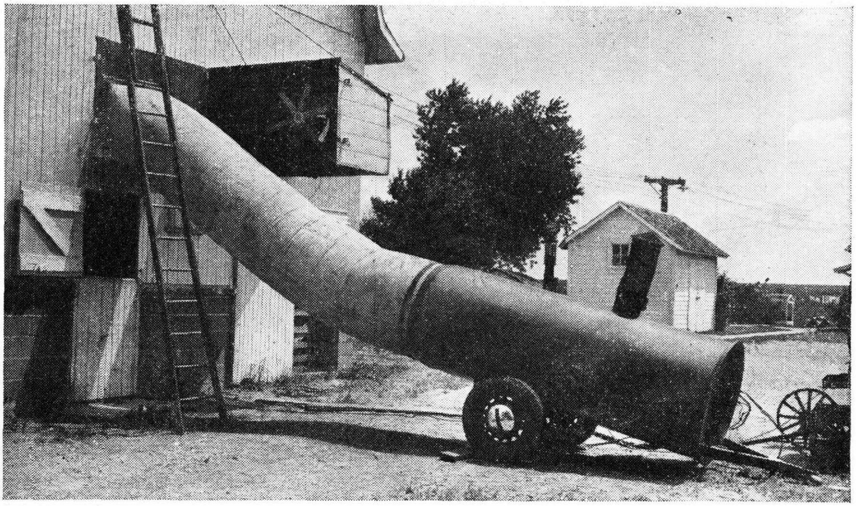

***Figure 13.*—Portable drier connected to duct system in a barn.**

drained concrete floor would be preferable but is not necessary (fig. 14).

Adequate ventilation should be provided above the hay and out the building so that the moisture-laden air can be carried out of the mow. Recirculation of moisture-laden air through the drying system should be avoided. Obstructions on the mow floor, such as posts, braces, and hay chutes, are objectionable, but an air-distribution system can usually be designed to reduce the effect of these obstructions. It must also be made certain that the building is sufficiently strong to support the additional weight of the green hay to be placed upon it. The extra weight of green hay may double or even triple the normal load.

OPERATION AND MANAGEMENT OF THE DRIER

Successful forced-air drying depends to a large extent on the proper operation and management of the drier. Management of the drier starts when the mower goes into the field to cut the hay. To obtain the best quality forage, it must be cut at the proper stage of maturity. For instance, alfalfa should be cut at the one-tenth to one-fourth bloom stage. In some sections where the weather favors rapid drying in the field, alfalfa can be mowed in the morning and by afternoon be dry enough to store, or it can be cut in the late afternoon and stored the next day. Under less favorable conditions it is necessary to leave the hay in the field for longer periods. After it has been in the swath for 2 to 4 hours on a clear day, the hay should be raked into small, loosely turned windrows. A side-delivery rake is desirable for this purpose. The hay should be placed in the mow just before it is dry enough for the leaves to be lost by shattering when handled.

In placing the hay on the air-distribution system, use machinery wherever possible. This reduces the amount of labor necessary and in most cases enables the operator to do a better job. The hay over the system should be distributed evenly. It should be packed only as much as is necessary to accomplish uniform distribution of the

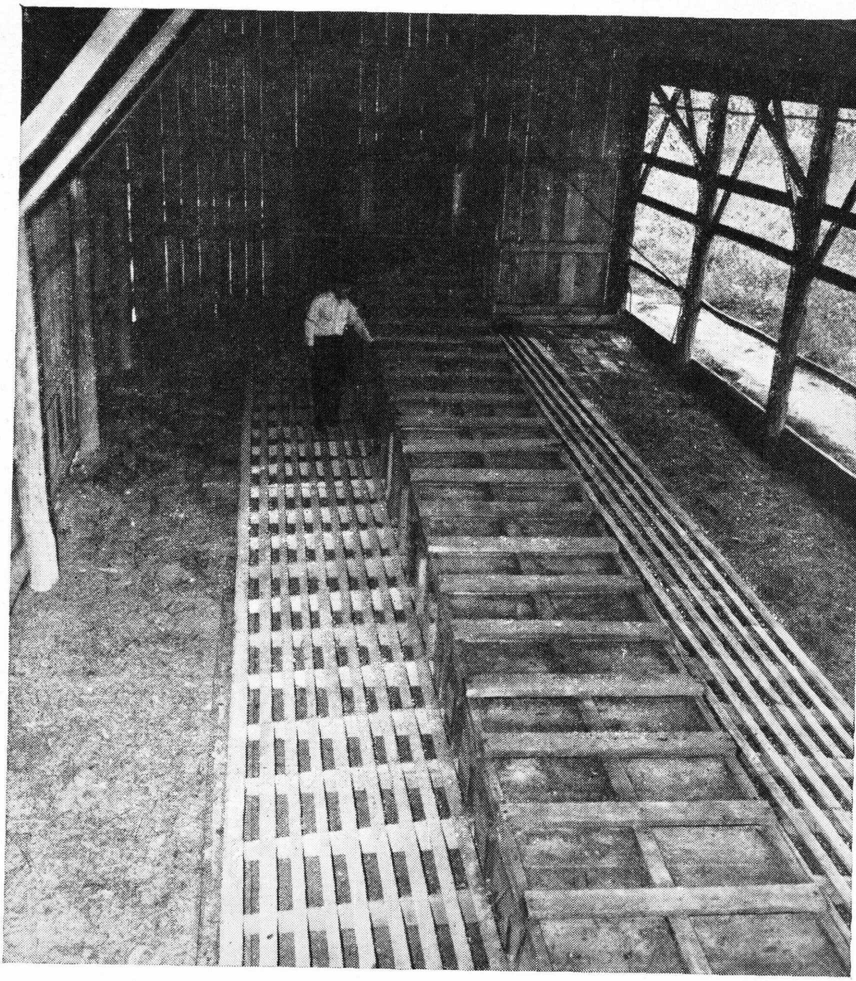

Figure 14.—Drying installation in an open shed.

hay. The first hay put on the drier should not be less than 4 nor more than 8 feet deep. After this is dry, additional hay may be placed on top. No additional loading should be more than 6 feet deep. Care should be taken not to exceed the maximum depth for which the system is designed.

To reduce the cost of drying with unheated air, schedules for operation of the fan have been devised. A typical schedule for operation of the fan is to run it continuously for the first 4 or 5 days, or until dry areas appear on top; then operate it for 1 hour out of 4 at night or during periods of rain or fog. Operate continuously during the day. Other schedules have been developed to fit local conditions.

When heat is used, the forage dries faster. The fan may be operated continuously regardless of weather. The temperature of the air leaving the hay should not be more than about 5° F. above the outside air temperature. If the temperature of the air leaving the hay ex-

ceeds this, the rate of fuel consumption should be reduced to bring it within this limit. The fuel consumption should be reduced as drying progresses until the heater is shut off entirely. Operation of the heater after the dry areas appear on top is not recommended.

To operate the fan after the hay is sufficiently dry to store safely is wasteful and to stop it too soon is false economy. Therefore, it is important to know when the hay is dry enough to keep safely. There is a relatively simple way to determine this. When the top 2 feet of hay feel dry, turn the fan off for a period of about 12 hours. At the end of that period turn the fan on and immediately walk over the top of the hay in the mow to determine if any warm air is rising from it. If warm air is felt, operate the blower on schedule for 2 more days and repeat the test. If no warm air is felt, turn the fan off and wait 24 hours longer and repeat the test. If no warm air is felt after the 24-hour period, the hay is dry enough for storage.

LABOR AND EQUIPMENT REQUIREMENTS

The labor and equipment needed to harvest forage for forced-air drying will vary from one farm to another, depending to a large extent upon the equipment available, weather conditions, and management of the operations. With good management much of the standard harvesting equipment can be used successfully in handling partially dried forage. However, it is desirable to use loaders of heavy construction when handling long hay of high moisture. Side-delivery rakes are preferred for use in raking, as dump and buck rakes have not been entirely satisfactory. Chopping partially dried forage from the windrow to wagons with field choppers eliminates much hand labor and hard work. Chopping with a machine set for length of cut of 3 inches or more is desirable; 2-inch cuts should be the minimum. The long cuts promote better drying conditions when placed on the drier and long-cut hay is more easily handled with a fork. Baling partially dried forage from windrows of changing moisture content requires frequent adjustments of the field baler to obtain the uniform-density bales most desirable for forced-air drying.

Equipment and practices used for placing chopped or long forage on a drier should be such that forage will be uniformly distributed over the entire drier. Walking on forage of high moisture causes excessive packing and uneven drying and should be avoided. One method of distributing long forage on a drier is to place the forage with an overhead fork on an unloading platform above the drier and distribute forage as desired by hand. The use of a tilting-platform "hay-mower" for distributing forage on the drier is less satisfactory than distributing from a platform by hand, because the forage tends to roll off the platform in large bunches rather than to slide off uniformly.

Blowers (fig. 15) are used to a considerable extent for placing chopped forage on driers, but distribution may be improved by use of conveyors (fig. 16). Blowers tend to segregate the leaves and stems of the forage as it is blown onto the drier. This makes uniform drying difficult.

Conveyors separate the forage less and require less power for operation than blowers. Partially cured baled hay should be handled with care to prevent breakage. Baled hay may be placed on driers most satisfactorily with an elevator or overhead fork (fig. 17). Dry-

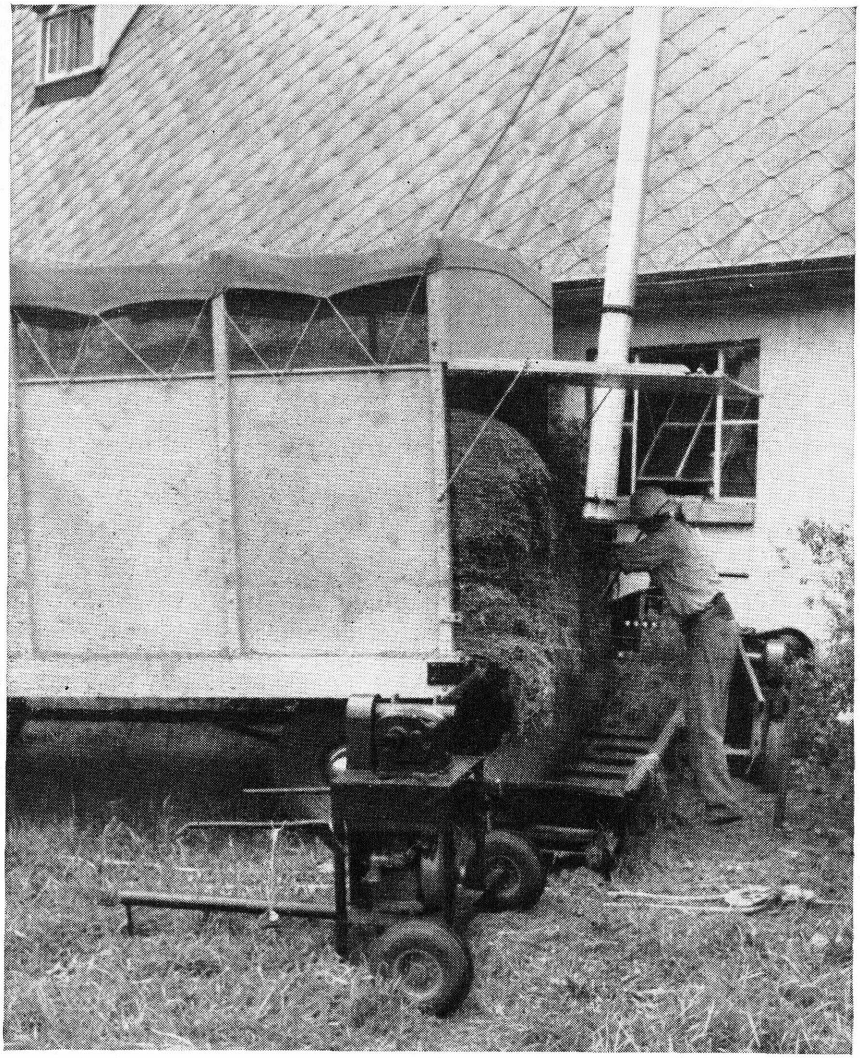

Figure 15.—**Blower elevating hay into the mow.**

ing is improved at times by placing a canvas over the top of the pile and part of the way down the sides. When this is done air passes around the bales, over the top, and out the sides of the canvas. This tends to dry the bales on the outside of the pile more uniformly and quickly.

Table 4 shows a comparison of the labor and equipment requirements for harvesting and storing alfalfa forage by four different methods under similar field and weather conditions. The labor and machinery requirements are based on a ton of dry matter preserved at time of feeding.

The same power mower and side-delivery rake were used for all methods of harvest. Field choppers with a two-man crew were used

Figure 16.—Conveyor for elevating hay into the mow.

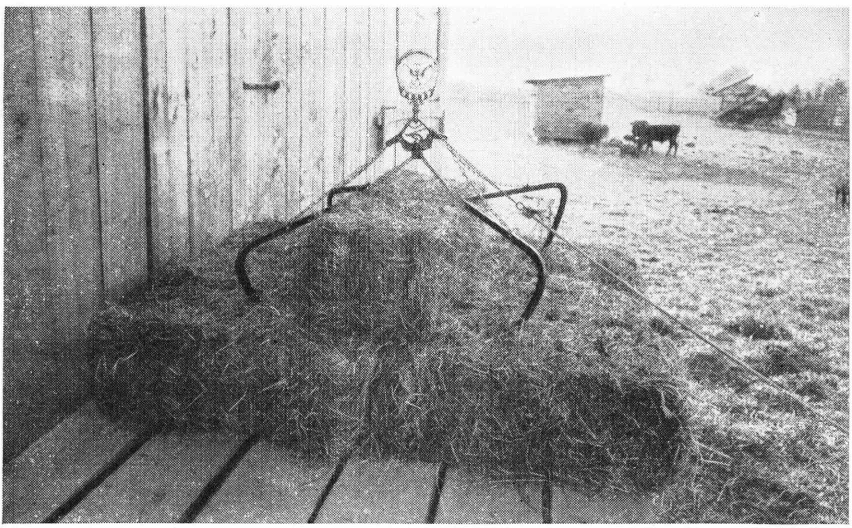

Figure 17.—Hay fork used for moving baled hay into storage.

TABLE 4.—*Labor and machinery hours required*[1] *in harvesting and storing alfalfa per ton of dry matter fed*

Labor and machinery hours	Dried by forced ventilation	Field-cured	Dehydrated	Silage
Man-hours	4.3	5.5	8.3	3.9
Tractor hours	1.8	3.7	1.5	1.8
Truck hours	1.8	.8	1.8	1.7
Mower hours	.4	.7	.4	.5
Rake hours	.3	2.5	.3	.4
Forage-blower hours	.7	----------	----------	.4
Field-chopper hours	.4	----------	.8	.5
Field-baler hours	----------	.6	----------	----------
Dehydrator hours	----------	----------	2.5	----------

[1] Actual operating time includes 18 minutes per load to and from field. Data are based on harvesting of 1 crop. The field-cured hay was rain-damaged.

for all methods, except for the field-cured hay, to pick up the forage from the windrow, to chop it, and to convey it into trucks. The field-cured hay was baled from the windrow, by one man operating tractor and baler. Bales were loaded onto wagons by hand and hauled to storage. A truck and driver and two or three men to do the loading were required for this work. A three-man crew consisting of the truck driver, blower operator, and a man in the mow or silo was necessary to unload the forced-air-dried hay and silage. A two-man crew consisting of a feeder and sacker was used to operate the dehydrator. Labor and equipment used to store the dehydrated sacked alfalfa was not included. The man-hour requirements for alfalfa dried with forced air, field-cured, dehydrated, and ensiled were 4.3, 5.5, 8.3, and 3.9, respectively. One man can be eliminated in drying alfalfa by the dehydrated method by blowing the alfalfa directly to storage without sacking. In the test recorded, this would have resulted in a saving of 2.5 man-hours. Tractor and rake man-hour requirements were much higher for field curing than for any of the other methods mainly because of the time consumed in turning the windrows.

EFFICIENCY OF HARVESTING

QUALITY OF FORAGE PRODUCED BY FORCED-AIR DRYING COMPARED WITH OTHER METHODS

The type of equipment used for any one method of harvest will vary considerably, depending upon the preference of the operator and the equipment that is available. The efficiency attained in preserving nutrients and dry matter, the quality of the forage produced, and the feeding value depend to a considerable extent on the method of harvesting and, in varying degrees, on the curing weather.

Cooperative studies were made on the four principal methods of harvesting (forced-air drying, field curing, wilted silage, and dehydration) to determine the comparative quality and feeding values of crops dried by these methods under favorable weather condi-

tions and also in periods of frequent rains and high humidity. The studies extended over a 4-year period and included 22 comparisons on 6 cuttings of alfalfa (table 5).

TABLE 5.—*Feed nutrients preserved in harvesting alfalfa by 4 different methods after 6 months of storage*

Method of harvesting	Number of harvests	Dry matter	Protein	Carotene
Field-cured hay:		*Percent*	*Percent*	*Percent*
Not rain-damaged	3	76	69	2.7
Rain-damaged	2	63	55	.6
Hay dried by forced ventilation:				
Natural air	3	83	79	7.8
Natural air with supplemental heat	5	86	80	11.8
Dehydrated hay	4	90	79	23.6
Wilted silage	5	83	83	20.3

Alfalfa partially cured in the field to approximately 40-percent moisture (wet basis) was finished on the drier, using outside air with or without heat added, as required for the comparison. When heat was added, the air temperatures were raised to as much as 25° F. above atmospheric temperature for most of the drying period. This amount of heat reduced the drying time in the barn as much as 60 percent, under weather conditions of high humidity.

Although fresh green forage may be dried with the portable dehydrator, the forage for this test was picked up from the windrow instead of from the standing crop because the type of equipment necessary for this operation was available for harvesting. Little field drying took place during the hour when the forage was in the swath and windrow. The dehydrator reduced the high-moisture forage to approximately 9 percent, and approximately 50 gallons of No. 2 fuel oil were required to produce a ton of the dried forage at the rate of approximately 800 pounds of dry forage per hour.

Forage harvested as wilted silage under favorable weather conditions usually must remain in the field approximately 2 hours if it is to dry to a moisture content of 60 to 65 percent, for storing without preservatives. If the cut forage has been rained on or if the weather is highly humid, longer periods must be allowed for adequate drying.

Carotene losses in forage occur at a very rapid rate during harvesting, curing, and storage. The longer the forage is exposed to the sun and weather, the greater the carotene loss. Carotene losses also occur during the drying process with forced-air driers and in the silo. The use of supplemental heat in forced-air drying speeds up the drying process and results in greater carotene preservation. Table 5 shows the percentage of carotene preserved in forage at time of feeding, approximately 6 months after cutting. Considerably larger percentages of the carotene were preserved in the dehydrated forage and the wilted silage than in the hay dried with forced air. The carotene preservation in field-cured hay was much less, and practically no carotene was preserved in field-cured hay that had been rained on several times.

Field dry-matter losses resulting from harvesting operations usually are greater as the forage becomes drier. Dry-matter losses often occur during curing or storing because of heat generated in the hay or of fermentation and spoilage in the silo. Protein losses occur along with dry-matter losses, mainly through the loss of the leaves or the whole plant and through leaching.

Compared with field-cured hay that had not been rained on, hay dried with unheated air retained 7 percent more dry matter and 10 percent more protein per acre (table 5); hay dried with heat added to the forced air retained 10 percent more dry matter and 11 percent more protein; wilted silage retained 7 percent more dry matter and 14 percent more protein; dehydrated hay retained 14 percent more dry matter and 10 percent more protein; field-cured hay that had been rain-damaged retained 13 percent less dry matter and 14 percent less protein.

In controlled feeding experiments, conducted by the Bureau of Dairy Industry, the different forages were fed at the same rate (dry-matter basis). In addition, the cows were fed a daily ration consisting of 1 pound of grain for each 3.5 pounds of 4-percent butterfat-corrected milk produced and 1.5 pounds of corn silage per 100 pounds of live weight. Under these conditions, milk production was about equal for all the forages harvested by the various methods with the exception of rain-damaged field-cured hay, on which milk production was lower. The relative feeding value of the different forages for milk production was found to be closely related to the total digestible nutrients available when fed.

In other experiments, the dairymen at the Virginia Agricultural Experiment Station studied the differences in feeding value of forced-air-dried and field-cured alfalfa hay. One hay was partially cured in the field and curing was completed by forced atmospheric air. Conditions for field curing the other lot of hay were very good, except for about one-third of the hay which was rained on with a few light showers.

After 6 months of storage, comparative feeding trials were made to determine the milk production of animals fed the two hays. Hay was fed as the sole roughage and the same amount was given to each group of cows. In addition, grain was fed according to the level of milk production.

The average daily milk production of cows fed hay dried with forced air was greater and the seasonal decline in production somewhat less than the production of cows fed field-cured hay. The cows fed hay dried with forced air produced at least 4 percent more milk than those fed field-cured hay.

Hay dried with forced air retained most of its green color and a larger percentage of its leaves.

Chemical analysis showed the protein content of forced-air-dried hay was 22.8 percent and for field-cured hay, 19.7 percent; this difference was highly significant. The percentage of fat was slightly higher in the hay dried with forced air, while the amount of crude fiber was higher in the field-cured hay; there was no appreciable difference in the ash content in forced-air-dried and field-cured hay.

The coefficient of digestibility was considerably higher for the forced-air-dried hay, being 74.3 percent as compared with 70.8 for the protein in the field-cured hay.

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